AN ICING PRODUCT DERIVED FROM OPERATIONAL SATELLITE DATA

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Abstract
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1. INTRODUCTION

The existence of super-cooled liquid water (SLW) in clouds is of concern to the general aviation community since it can freeze on contact with aircraft and adversely affect the aircraft's performance. Icing on the airframe can increase drag, decrease lift and cause control problems. The degree with which SLW will freeze and affect an aircraft's performance depends on several factors including the type and weight of the aircraft, the duration of exposure to SLW and the accretion rate of ice on the airframe. The severity of ice accretion is sensitive to temperature, the liquid water content and the drop size distribution (Rasmussen et al., 1992). Much attention has been given to improving the detection and forecasting of aircraft icing over the past decade. A number of temperature and humidity based diagnostic algorithms have been incorporated with numerical weather prediction models to produce icing forecast products over the United States (Schultz and Politovitch, 1992; Forbes et al. 1993). An intercomparison of in-flight icing algorithms was recently conducted by Thompson et al., 1997 and Brown et al., 1997. Those studies revealed that temperature and humidity based algorithms significantly over-predict the area coverage of SLW clouds. Thompson and Bullock (1997) showed that satellite data can be used to reduce the predicted spatial extent of SLW by excluding areas where the satellite-derived cloud top temperature is above freezing. Satellite data can also be used to detect SLW directly since it is often found to accumulate in the top several hundred meters of cloud layers (Rauber and Tokay, 1991). Recent advances in geostationary satellite sensors now permit us to derive cloud optical depth, particle size, phase and water path in near real-time. Ellrod (1996) and Ellrod and Nelson (1996) have shown the potential for using geostationary satellite data to detect SLW clouds. In this paper, we present a technique to derive the cloud optical properties of SLW clouds from geostationary satellite data. The satellite retrievals are co-located and compared with aircraft icing reports made by pilots (PIREPS). The potential for deriving an icing intensity index from the satellite data is explored.

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2. DATA AND METHODOLOGY

Recently, a suite of algorithms has been developed to derive pixel level cloud properties for the Clouds and Earth's Radiant Energy System (CERES) project (Minnis et al. 1995; 1998, 1999 and Arduini et al. 1999). These algorithms have been adapted and are being applied to Geostationary Operational Environment Satellite (GOES-8) data over the United States for the Atmospheric Radiation Measurement (ARM) program. Cloud properties are determined by matching radiance observations at 0.63, 3.9, 10.8 and 12.0 µm at a nominal 4 km resolution to parameterizations of model calculations of cloud emittance and reflectance for a wide range of water droplet and ice particle sizes (Minnis et al, 1998). Additionally, a robust cloud mask has been developed to exploit the multi-spectral information now available on operational satellites. The mask is a significant improvement over previous bi-spectral threshold (single-channel infrared) cloud identification techniques applied during the day (night), particularly in distinguishing clouds from snow and for nighttime low cloud and fog detection. Accurate maps of clear-sky surface albedo and emissivity have been developed (Smith et al. 1999, Sun-Mack et al, 1999) and are crucial to both the cloud identification and the cloud property

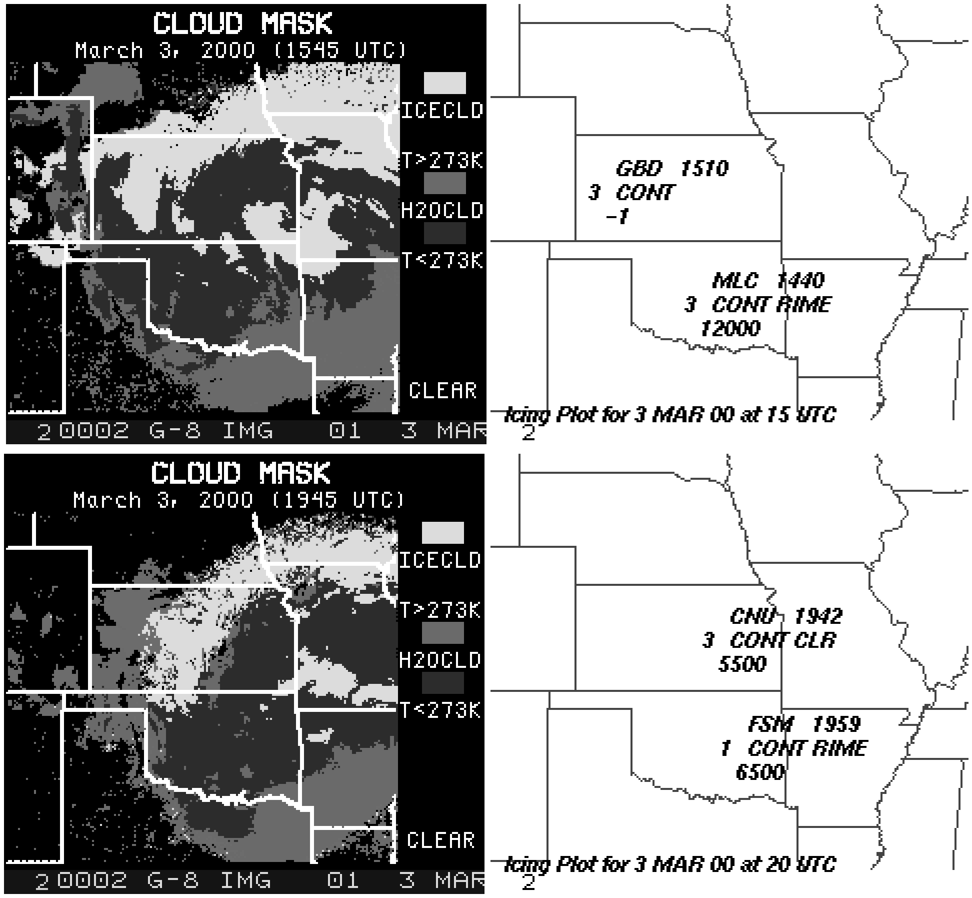

Fig. 1. Cloud mask, cloud phase identification and coincident icing PIREPs on March 3, 2000.

retrievals. The atmospheric contribution to the satellite radiances is separated from the cloud contribution. Atmospheric optical depths are calculated for the GOES-8 wavelengths following the method of Kratz (1995) and utilizing temperature and humidity profiles obtained from 3-hourly Rapid Update Cycle (RUC) operational analyses. Calibration of the 0.63 -µm channel is performed and follows the method of Nguyen et al. (1999). Nominal calibrations for the other channels are employed. These algorithms have been run operationally at 30-minute resolution since early March 2000 to derive cloud and radiation parameters from GOES-8 data taken over the southern great plains (SGP) of the USA for the ARM program (see http://angler.larc.nasa.gov/armsgp for examples of the cloud products).

2.1 Determination of SLW

In the satellite analyses presented here, clouds determined to be composed of water droplets with temperatures below 273K are denoted as SLW and indicate the potential for aircraft icing. The retrieval algorithm attempts to derive both an ice particle and a water droplet solution for each pixel. An unambiguous single solution is straightforward to interpret but dual solutions can be obtained which complicate the selection of phase. If both a water droplet and ice solution are physically realistic (i.e. both the water and ice models encompass the observations), then the phase is determined using consistency checks with:

1) The effective cloud temperature (T_c). Only water solutions are allowed for T_c > 273 K and only ice solutions are allowed for T_c < 233 K.

2) The 12.0 µm observation. The 10.8 – 12.0-µm brightness temperature difference is compared with model values for the ice and water solutions. If the pixel is determined to be optically thin, the solution that best matches the observations is chosen.

3) A cloud layer classification from a regional analysis of 0.65 and 10.8 µm data.

4) Default T_c threshold. If there is no other indicator, then clouds with T_c < 253 K are

classified as ice and clouds with T_c > 253 K are classified as water.

3. RESULTS

An example of the satellite-derived cloud product over the SGP is shown in figure 1. The left two panels show the cloud mask and phase identification at 1545 and 1945 UTC on March 3, 2000. The satellite analysis of this slow moving low pressure system indicate large areas of SLW. The right two panels depict icing PIREPS at 15 and 20 UTC. The PIREPS were de-cluttered for readability but there were over 80 pilot reports of aircraft icing in the SGP domain on this day. There is excellent agreement in the location of the satellite SLW and the PIREPs icing reports. Cloud optical depth, effective radius and water path are also derived (not shown) every 30-minutes. The retrievals show excellent temporal consistency as the solar geometry changes. Most of the retrieved water droplet radii were between 6 and 16 µm. Larger droplets could be seen near the ice clouds suggesting some cirrus contamination in the retrievals. In order to make a more quantitative comparison with pilot reports of icing, PIREPs for the entire month of March 2000 were obtained. The PIREPs include, among other variables, an estimate of icing intensity reported in octas, icing type (clear, rime or mixed), the aircraft altitude, temperature, latitude and longitude. A frequency distribution of the PIREPs icing intensity for March 2000 is shown in Fig. 2. Fig. 2 also includes the frequency of negative icing reports. Negative icing reports are reports of 'no icing'. Brown et al. (1997) discuss some of the biases associated with PIREPs For example, the low frequency of negative PIREPs results from the fact that there is little incentive to report 'no' icing but a lot of incentive to report positive icing. The distribution for March 2000 is similar to the distribution for other winter months, in other years and over the entire continental USA with the possible exception of a relatively low percentage of reports in the moderate category. GOES-8 cloud properties were retrieved in a 0.5 degree lat/lon region encompassing every daytime icing PIREP in the SGP domain during March for comparison. The temporal matching between the satellite data and the reported PIREP time was restricted to +/- 15 minutes. There were a total of 630 matches, 458 of which contained

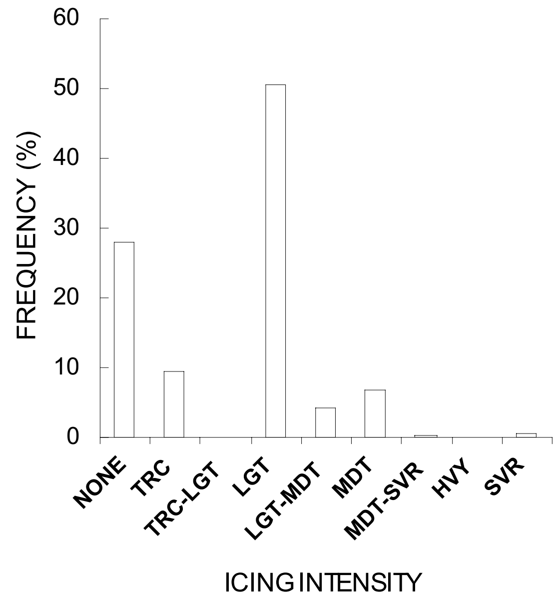

Figure 2. Frequency of icing intensity PIREPs over the SGP during March, 2000

positive icing reports. The remaining 172 matches contained negative icing PIREPs. One limitation to using satellite data to detect SLW clouds is the fact that higher level ice clouds may obscure SLW clouds from the satellite field of view. Fig. 3 depicts the percentage of positive icing PIREPs as a function of ice cloud fraction derived from the satellite data. For the SGP during March, it appears obscuration by overcast higher level ice clouds occurs about 35% of the time. For all the positive icing PIREPS, the satellite retrieval algorithm detects SLW clouds 98% of the time

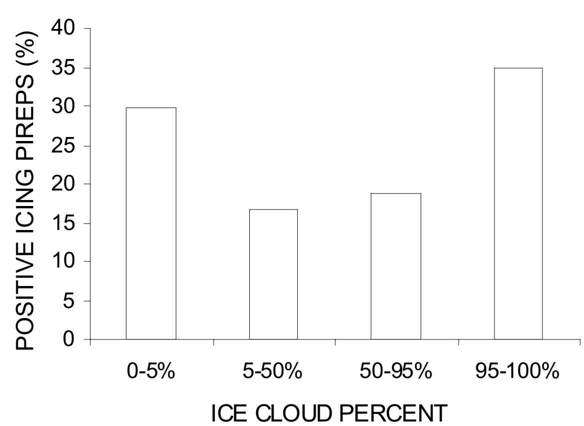

Fig. 3. Distribution of high level ice clouds derived from GOES-8 in the vicinity of positive icing PIREPS

providing there are no overcast ice clouds (ice cloud fractions < 95%). For scenes with ice cloud fractions less than 5%, SLW was detected by the satellite in 95% of the positive icing PIREPs cases. This implies good agreement between the satellite SLW detection algorithm and postive icing reports. It is also desirable to know what percentage of the satellite SLW retrievals are false. In 66% of the negative PIREPs cases, the satellite detected SLW cloud fractions greater than 5%. It appears that PIREPs cannot be used reliably to predict the satellites false alarm ratio for SLW (Brown et al, 1996). The biggest incentive for negative icing reports is probably to contradict previous postive icing reports.

4. CONCLUDING REMARKS

A technique for deriving cloud optical properties and, in particular, SLW, from high spatial and temporal resolution satellite data has been described. Initial comparisons with pilot reports of icing are encouraging. It is still unclear how useful PIREP's will be for validating the satellite SLW retrievals. Certainly, it is unlikely that negative icing PIREPs will help us understand the false identification of SLW by the satellite technique. It is intended that the satellite analyses will be performed over at least a few more winter months to increase the statistical sample. Pilot reports of icing intensity will be correlated with satellite-derived liquid water path and cloud temperature to explore the potential for developing an intensity index from the satellite retrievals.

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